Mars Exploration Rover Mobility and IDD Downlink Analysis Tools

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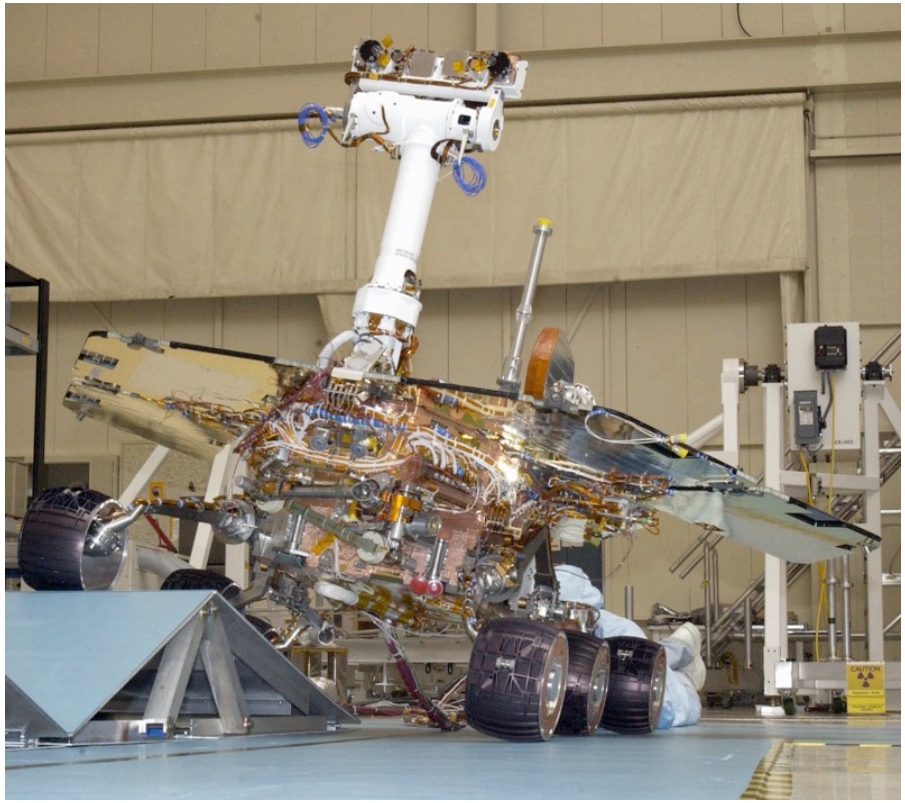


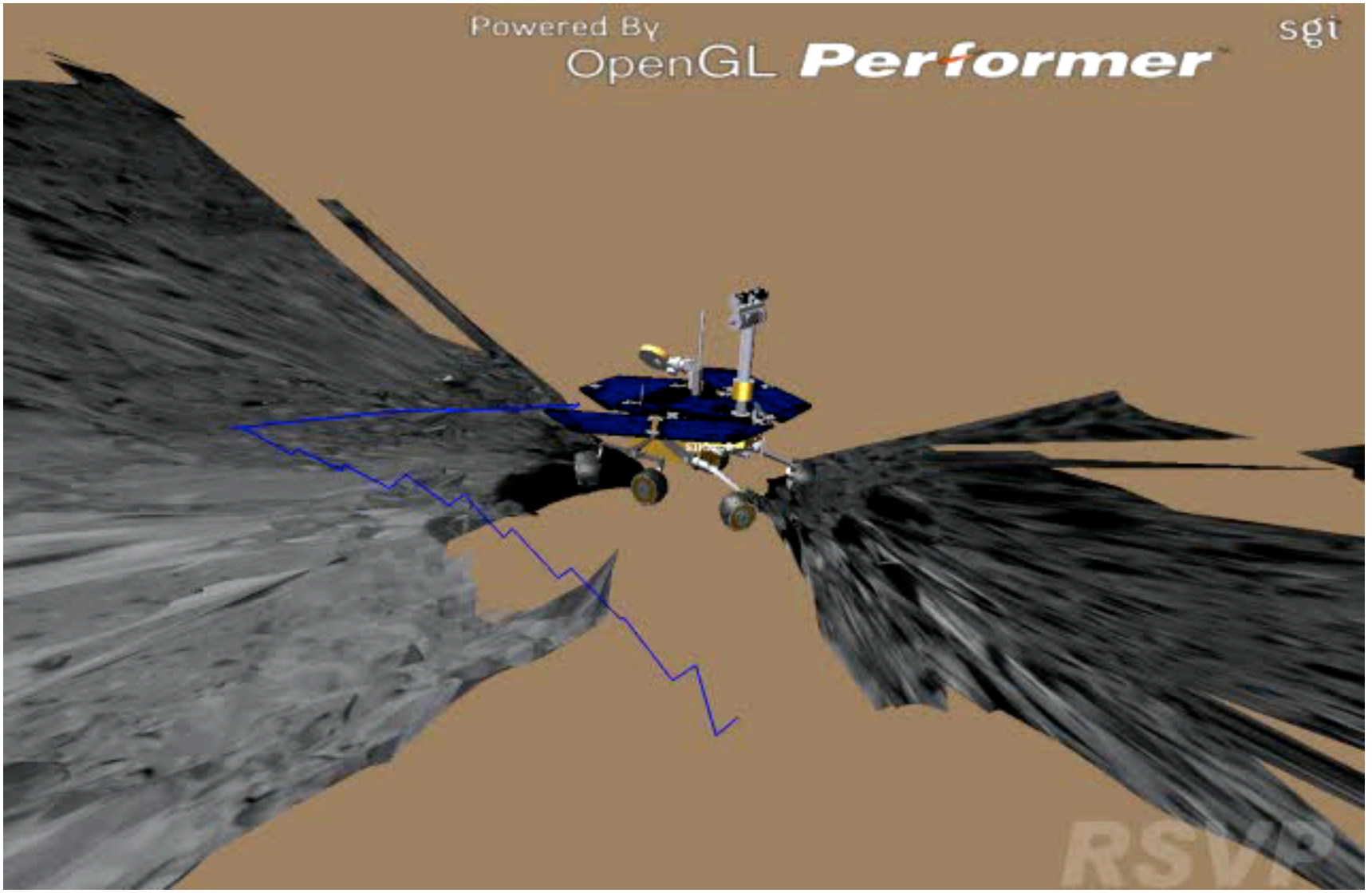
Overview

- **Driving and operating the arm on the Mars Exploration Rovers daily requires a rapid understanding of what happened during the previous day.**
- **This immediate ("tactical") analysis must be performed:**
  - Even when only a *partial* view of what happened is available,
  - By people who may be working over a slow remote connection,
  - Quickly enough to be useful to the current day's planning activities.
- **Long term ("strategic") analyses are also needed:**
  - To understand the recent multi-day history of a stalled actuator
  - To monitor overall vehicle health during the entire mission
- **In this paper we describe some of the primary tools used by the operations team to monitor the mobility and Instrument Deployment Device (IDD, i.e., the rover's arm) subsystems.**

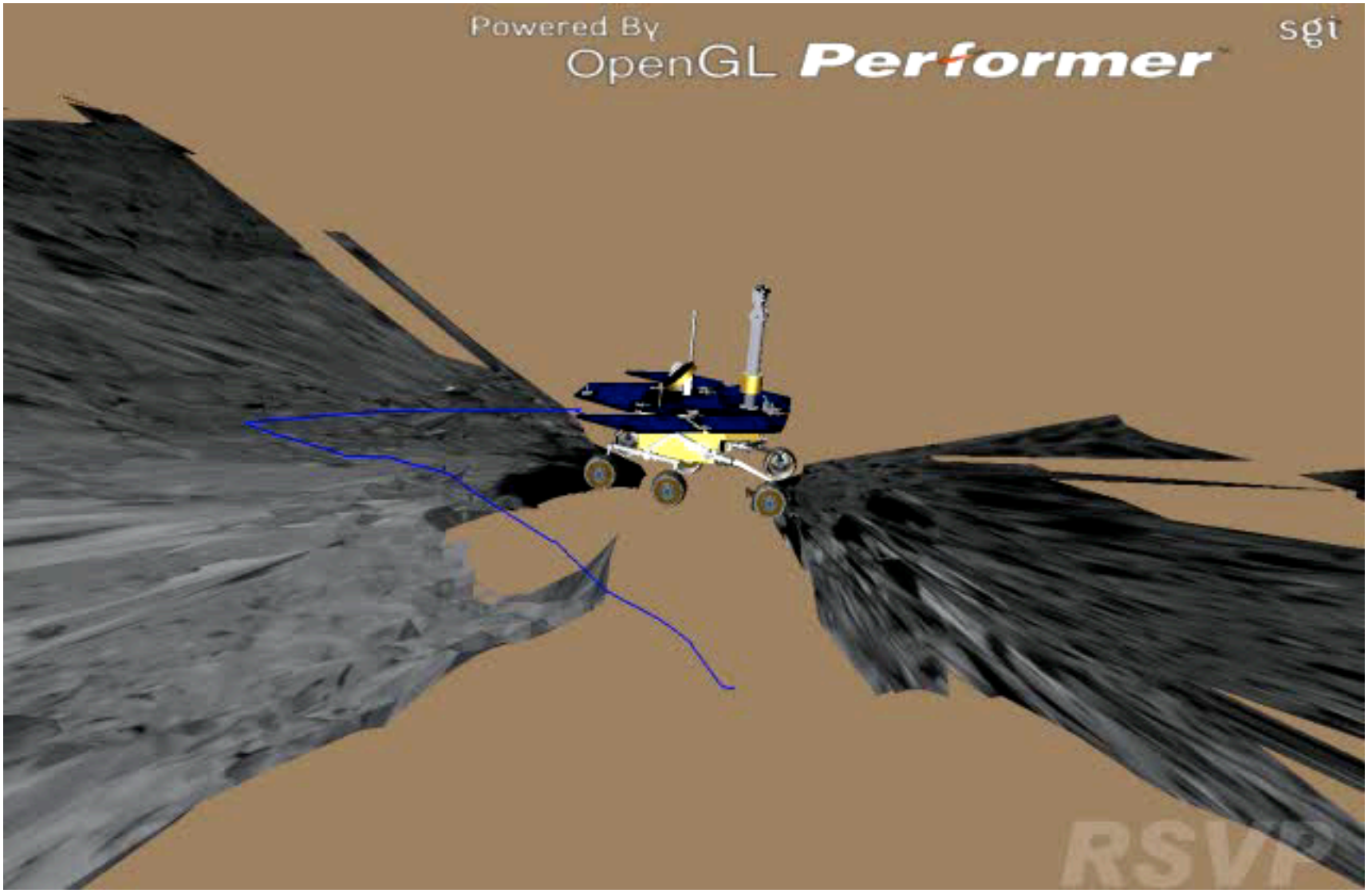
Day-long Activities

- **Activities that span the Martian Solar Day (1 "sol" ~ 24.6 hours) are logged into Rover Kinematic State files:**
  - These XML files include values of actuator motor angles (and vehicle position and attitude) at specific times, allowing visualization of a whole sol's activities in the RSVP tool
    - Most activities have many long pauses, which we remove for playback
    - See example animations of sol A-208 drive
    - See example animation of IDD activity inside trench

MER-B Raw Downlink data



MER-B Smoothed Data



Arm Activity

Report Summaries

- **Text-based reports summarize all interesting events of the sol**
  - Slip Amounts
  - Arm placement errors
  - Course Plot
  - Image thumbnails

Overall Web Page: Mot-all-report

File Edit View Go Bookmarks Tools Window Help

Motion History Reports - Summary of products between SCLK 243770530.59309 and 243859305.59309

Includes data products from:

- /home/mwm/a/1323/ssw/products/created

Raw Jump-corrected Total Distance from corrected_poses: 19.22 meters

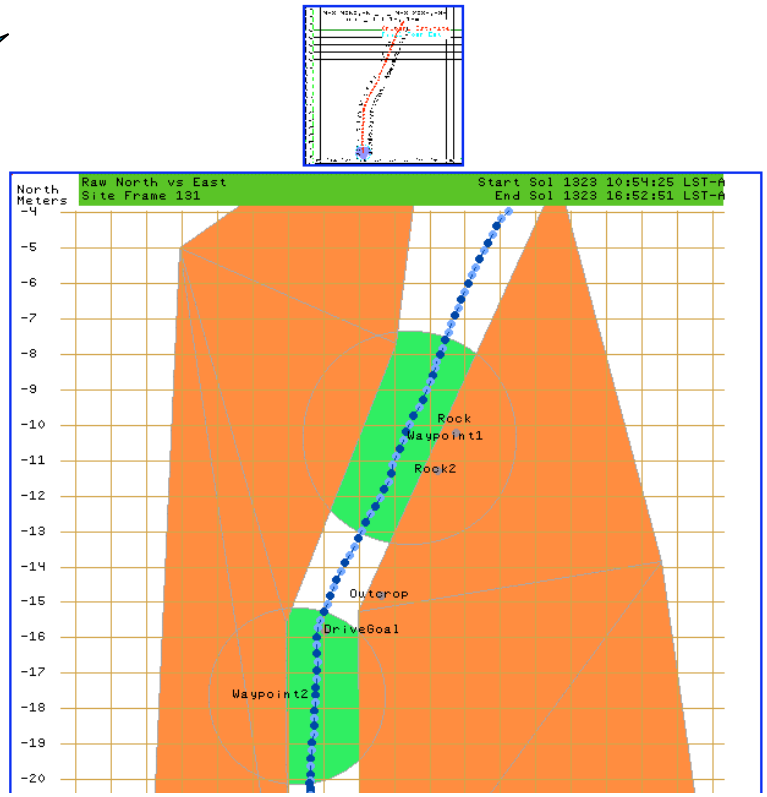
Raw Total Distance (during this period) from motion history: 19.542739 meters

Raw Total Distance (during this period) from step summary: 19.219 meters

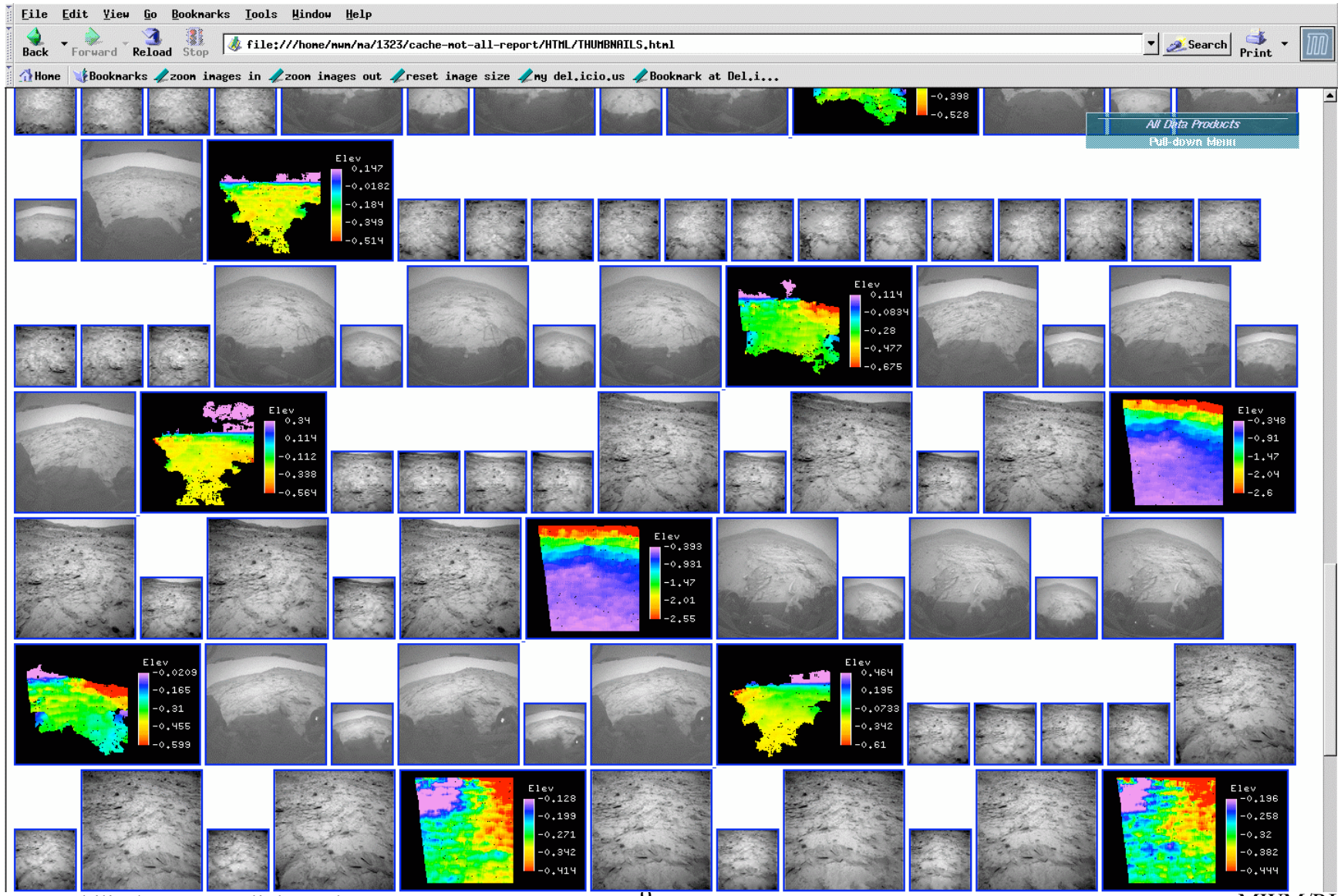
Pull-down menu for data products

All Data Products
Pull-down Menu
EHA Plots
EHA Summary
EVR
THUMBNAILS
DP Summary
IDD Summary Report
Left FRONT HAZCAM ICER
Left NAVCAM ICER
Left PANCAM ICER
Right PANCAM ICER
Left REAR HAZCAM ICER
Left NAVCAM LOCO
Left PANCAM LOCO
Right PANCAM LOCO
Left FRONT HAZCAM Thumbnail
Right FRONT HAZCAM Thumbnail
Left NAVCAM Thumbnail
Right NAVCAM Thumbnail
Left PANCAM Thumbnail
Right PANCAM Thumbnail
Left REAR HAZCAM Thumbnail
Right REAR HAZCAM Thumbnail
MOBM Kinematic State
MOBM Parameters
MOBM Summary
MOBM Traverse History
MOT Parameters
MOTB Run Position
NAV Diag
NAV Map
PTY Output
SAPP Knowledge
Hyper Plots
Annotated Sequences
Annotated Trace
All EVRs (text only)
Downlink Report Template

General Mobility Summary



Sample Data Products: Image Thumbnails



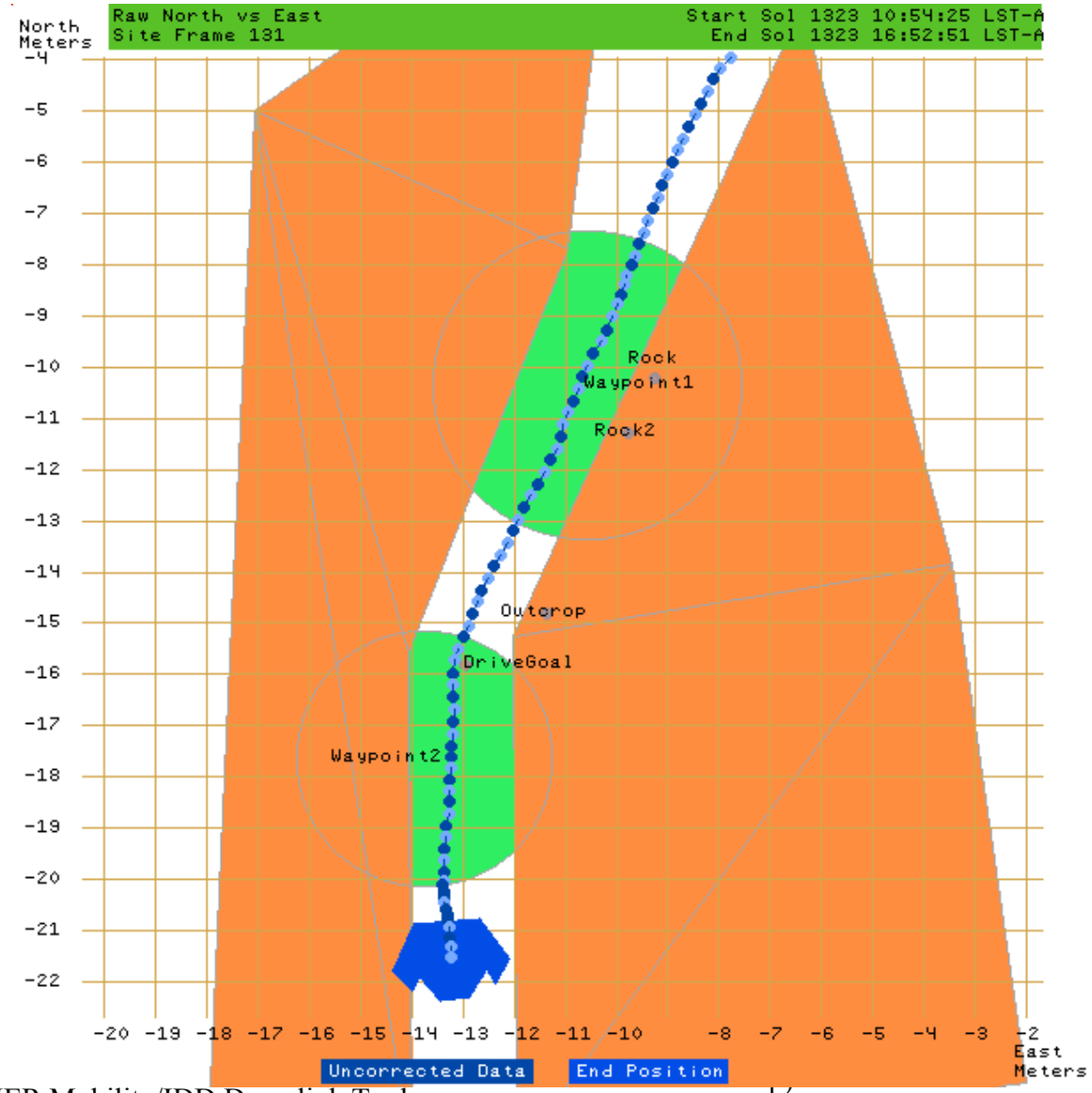
Sources of Engineering Data

- **The MER missions generate 3 primary types of data:**
  - Text messages (Event Reports, or “EVRs”, like printf’s)
  - Sparsely sampled scalar values (Engineering, Housekeeping and Accountability, or EH&A), with very coarse timestamps
  - Detailed Data Products, which are binary files that follow a documented format
- **We might receive only bits and pieces of all the data generated on any given sol (Mars day).**
  - It might be days or weeks before data is received on Earth
- **On Earth, these data are automatically written to files based on the sol on which they were created**

Dealing with Partial Data

- **Each rover generates dozens or even hundreds of separate pieces of data each sol**
- **Not all generated data is received at Earth the same day**
  - There is limited bandwidth throughout the communication chain
    - (rover -> orbiter -> deep space network)
  - Bad weather at the Deep Space Network antenna could corrupt data
- **Certain information is replicated in many forms**
  - E.g., rover X,Y,Z position appears in EH&A, certain EVRs, and multiple data products
- **Over 600 distinct fields are automatically extracted from multiple sources and given a unique name**
  - Users generally do not care exactly how the information was collected (I.e., the source of the data), but they do want to see every value downlinked
    - Example: Course plot

Dealing with Partial Data: Sample Course Plot



(X, Y, Z) position knowledge may come from many sources:
Text messages, EH&A, or different Data products, e.g.:
- Images,
-Mobility Summary,
- Mobility Details

-Hyperlinks connect blue dots to details of each step

Text-based Database files

- **All data is stored in plain-text spreadsheet files, with annotations**
  - We use Column Separated Values with annotations; “ACSV” files
  - This makes inspection and validation easy, and allows rapid query generation using UNIX command-line tools (e.g., awk, perl)
  - They might be large, but Disk is Cheap

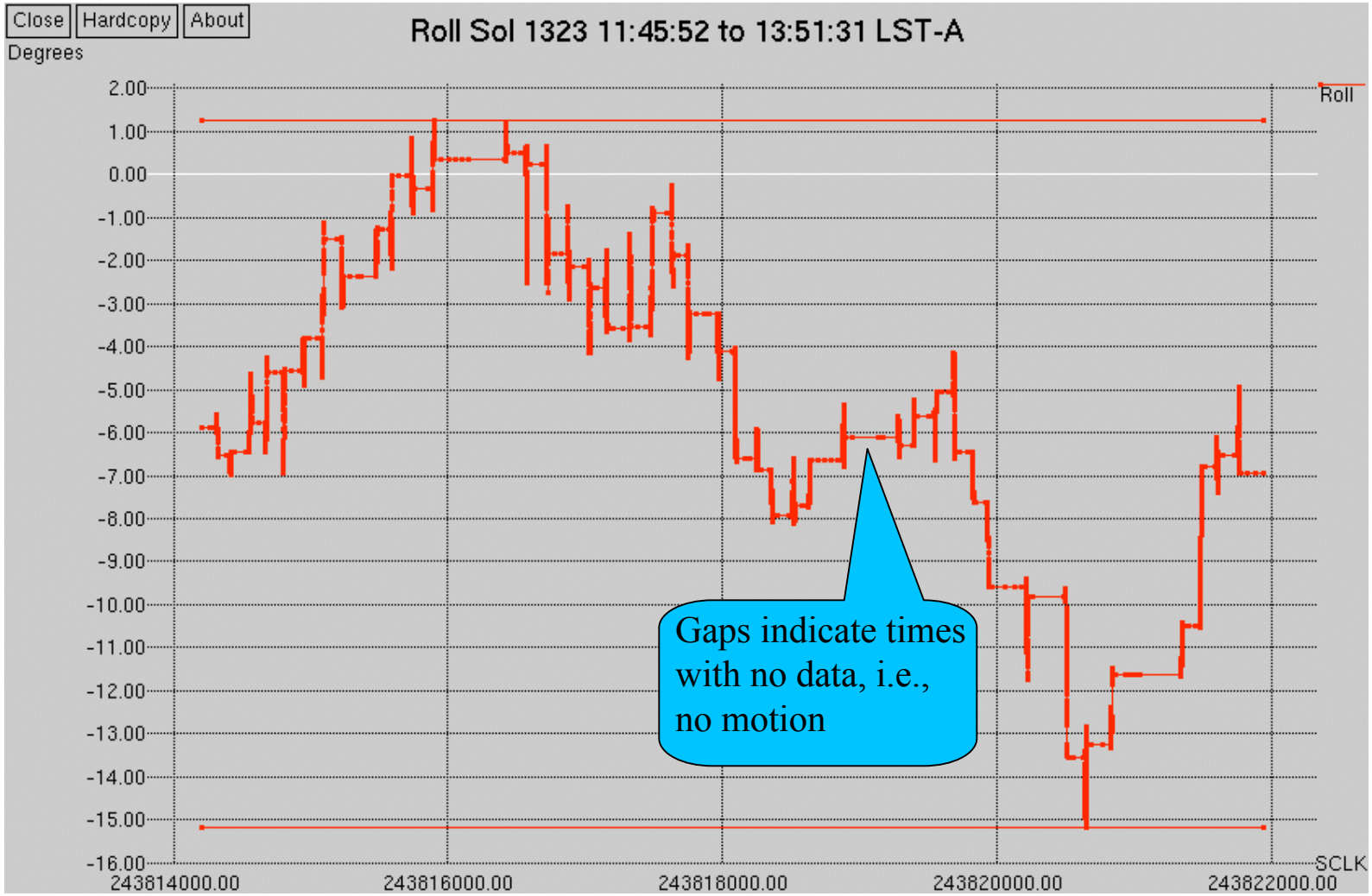
```
# MER NAV Datasets  corrected_poses 3 ($ Id $)
#  1            SCLK sclk                %13s    seconds
#  2   Command Start f_start_sclk        %13s    seconds
#  3    Command Name f_command           %s
#  4        Duration f_step_duration     %6.2f   seconds
#  5        Hazavoid f_hazavoid          %s
#  6       Tolerance f_goal_tol          %2.2f   meters
#  7       Step Size f_step_size         %4.2f   meters
#  8      Site Frame f_rmc_site          %3d
#  9     Drive Index f_rmc_drive         %3d
# 10      Corr NORTH f_corr_north        %9f     meters
# 11       Corr EAST f_corr_east         %9f     meters
# 12       Corr DOWN f_corr_down         %9f     meters
# 13            Roll f_roll              %9f     radians
# 14           Pitch f_pitch             %9f     radians
# 15             Yaw f_yaw               %9f     radians
# 16            Tilt f_tilt              %9f     radians
#                .........
# 39         Mission f_mission           %s
# 40          Source f_source            %s
```

Interactive Queries

- Normally you want to see engineering field values without worrying about the precise source of the data (EVR, EH&A, Data Products)
- Query times span just the current "working" sol by default, but can be extended to cover the whole mission

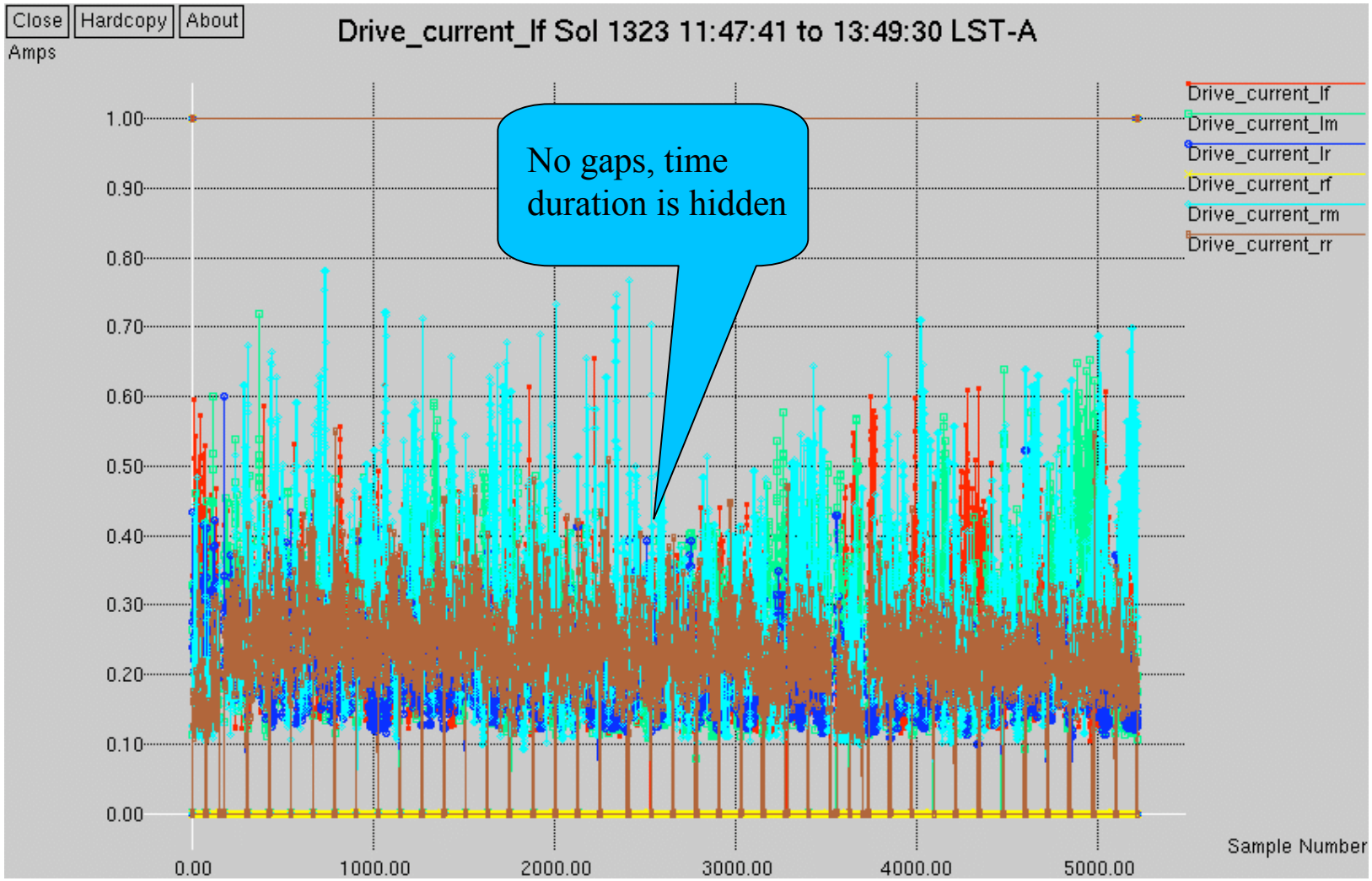
- The following slides show examples of interactive queries:
  - `showme roll`
  - `showme -samples drive_current`
  - `showme -commands pitch`
  - `showme -start 12:30 -end 13:15 tilt`

Plots of One Field vs Time

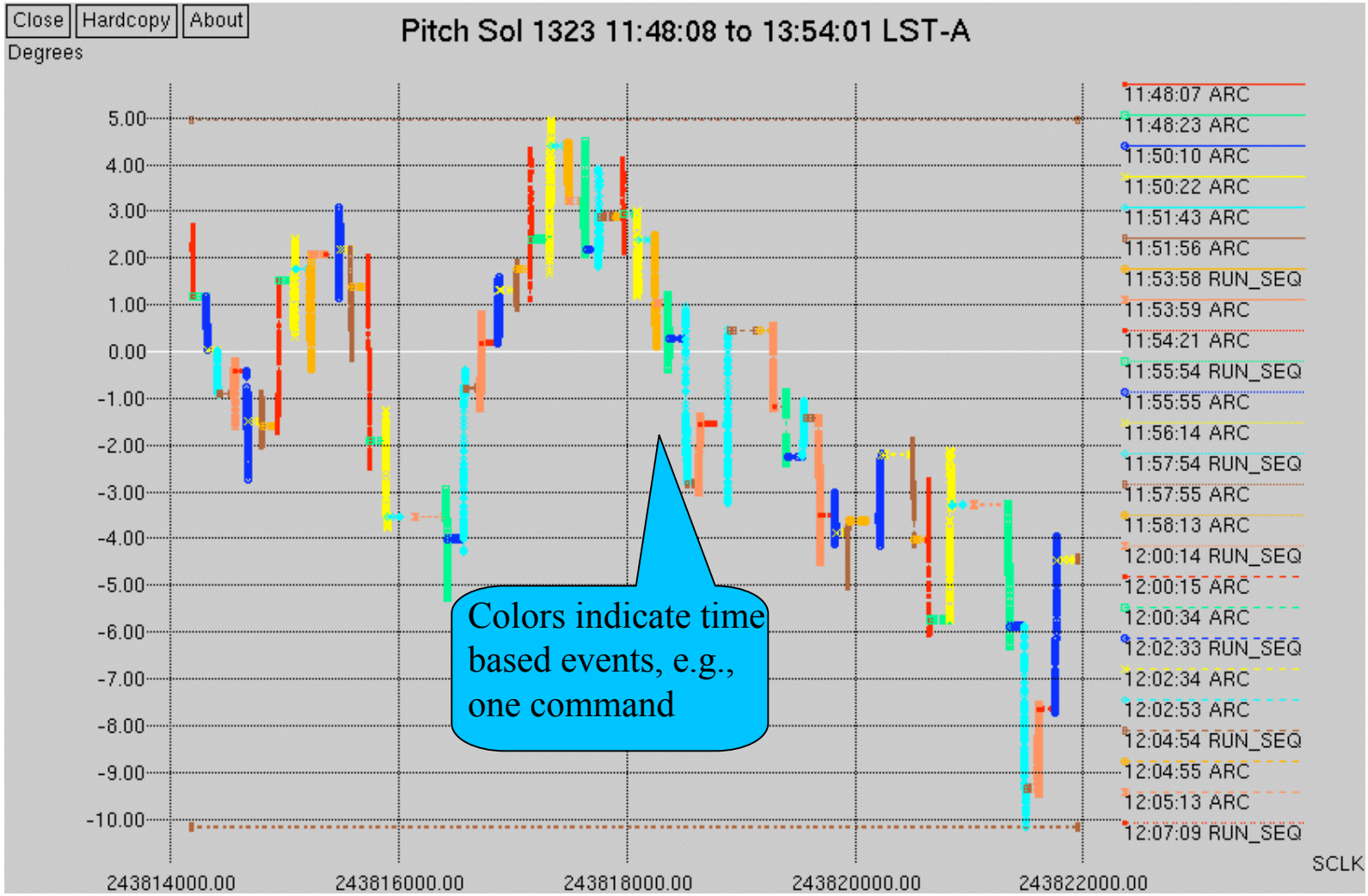


(All graphs can be zoomed-in)

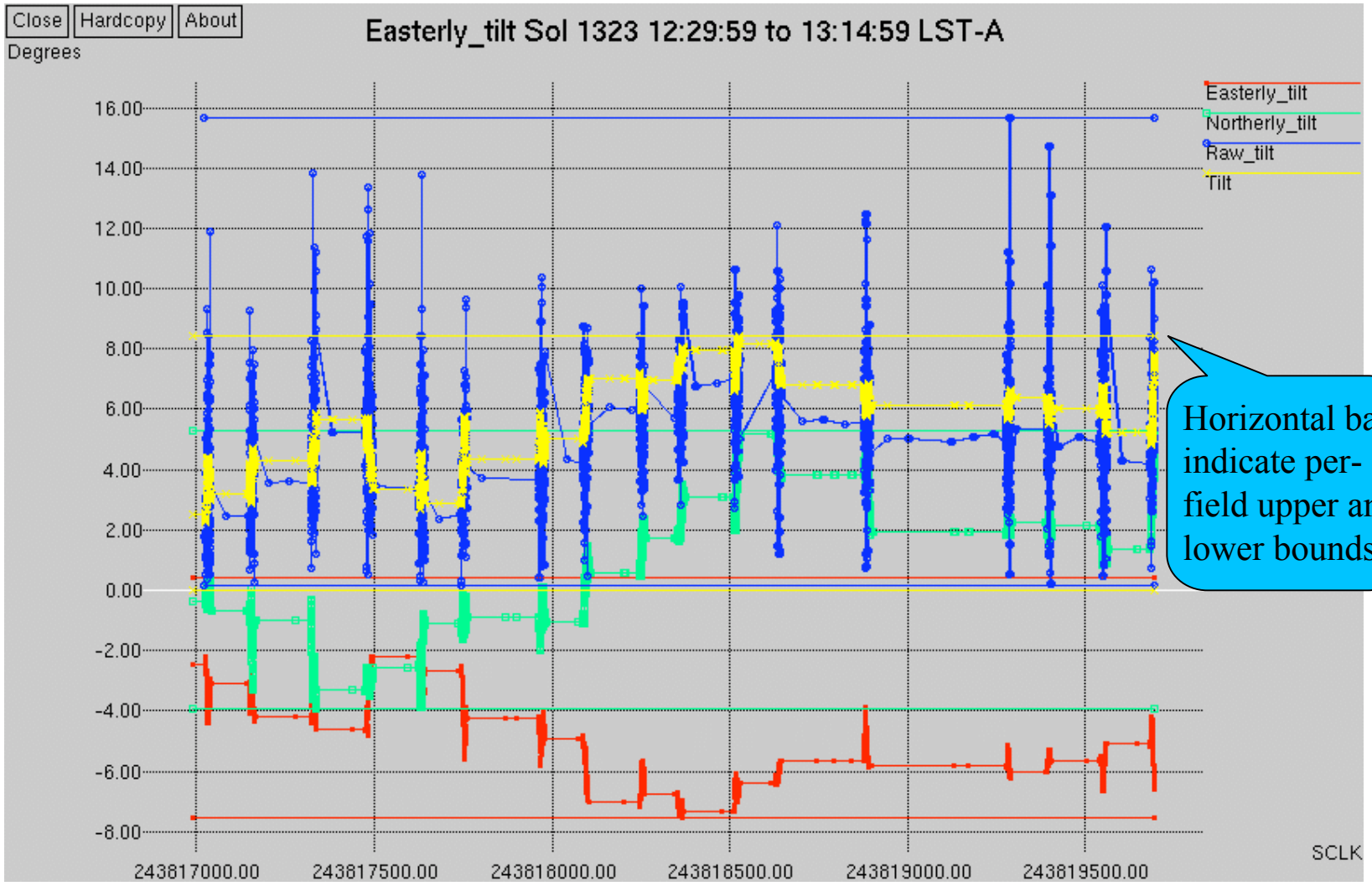
Plots vs Samples Instead of Time



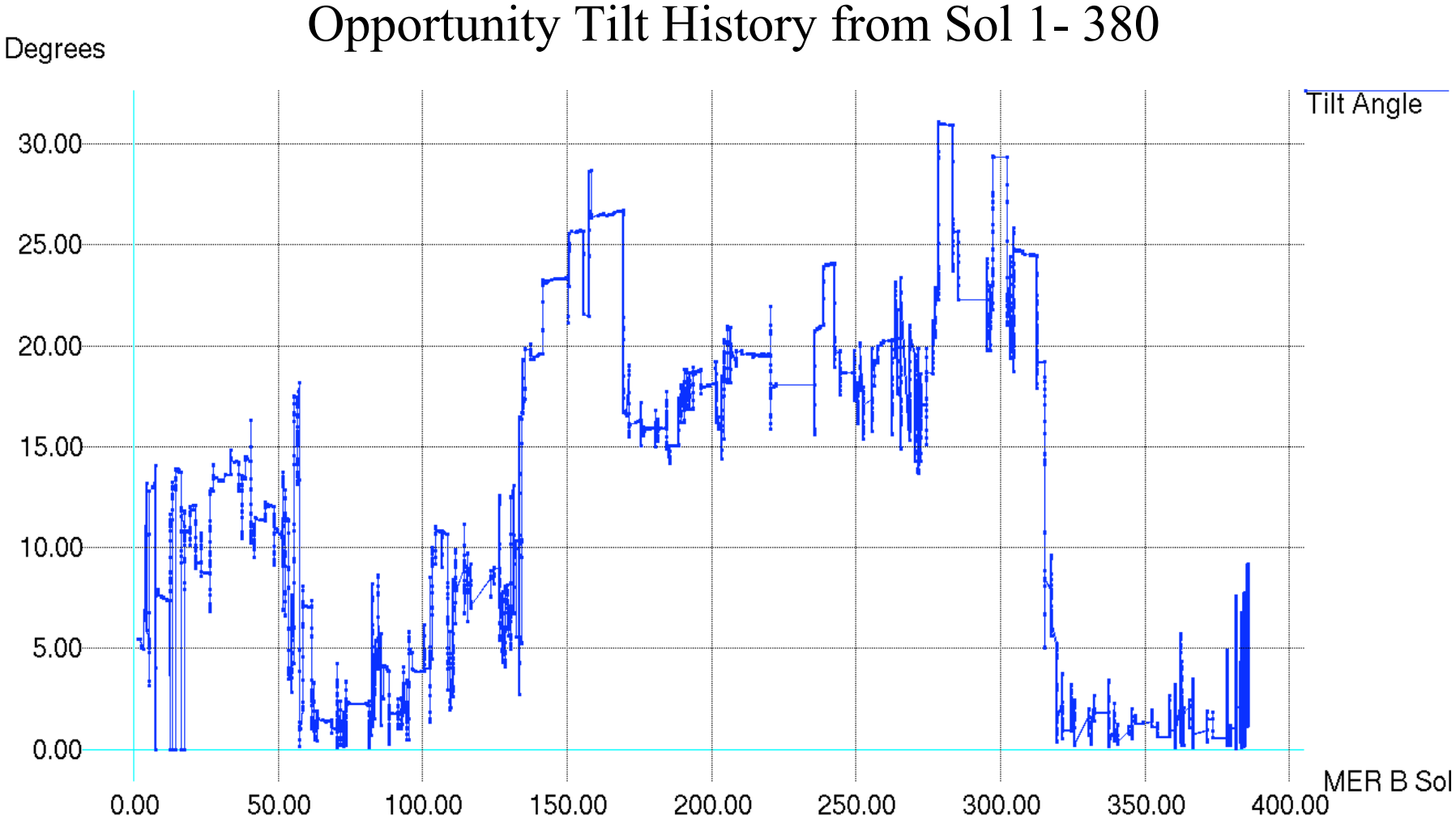
Plots Can Include Command Annotations



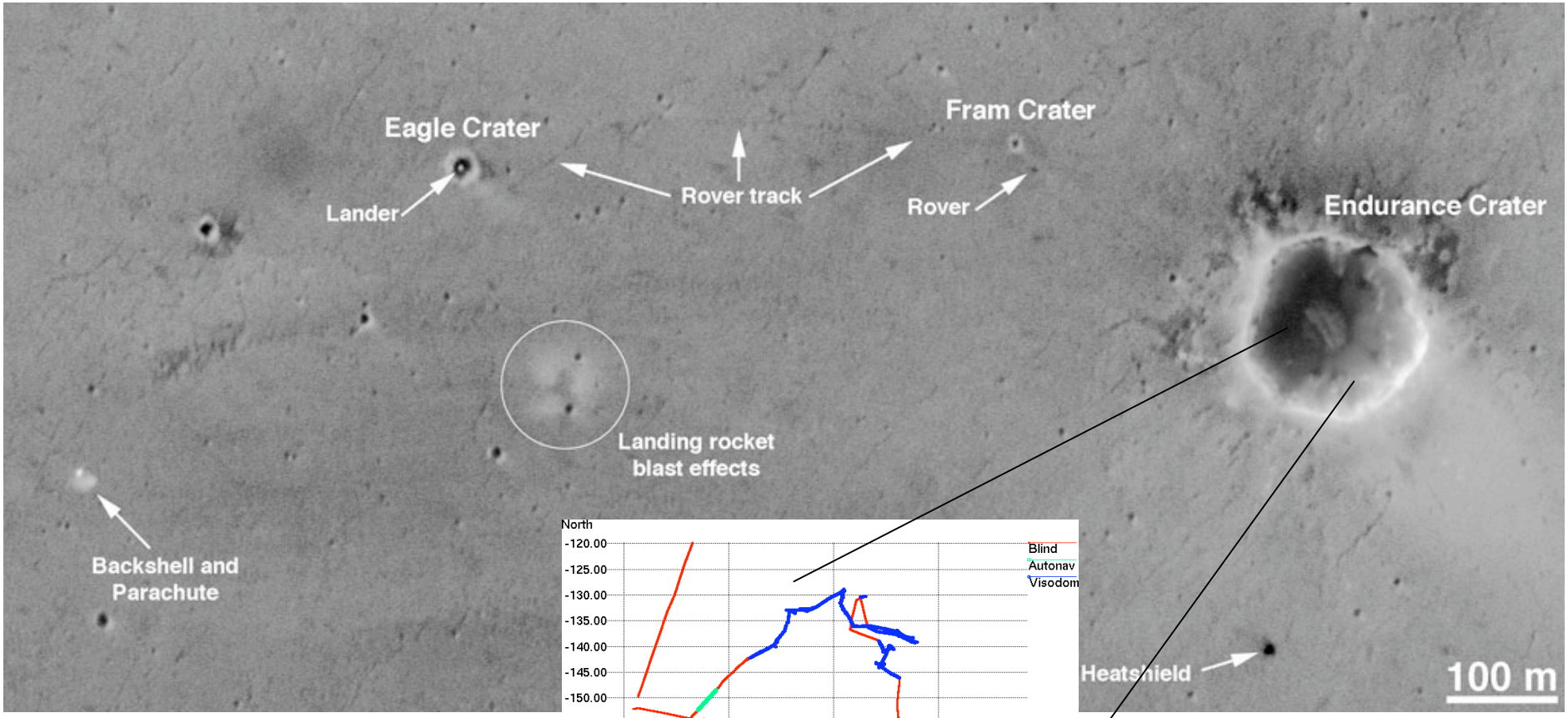
Plots Can Include Multiple Fields



Plots Can Span More Than a Year



Opportunity Drive to Endurance Crater

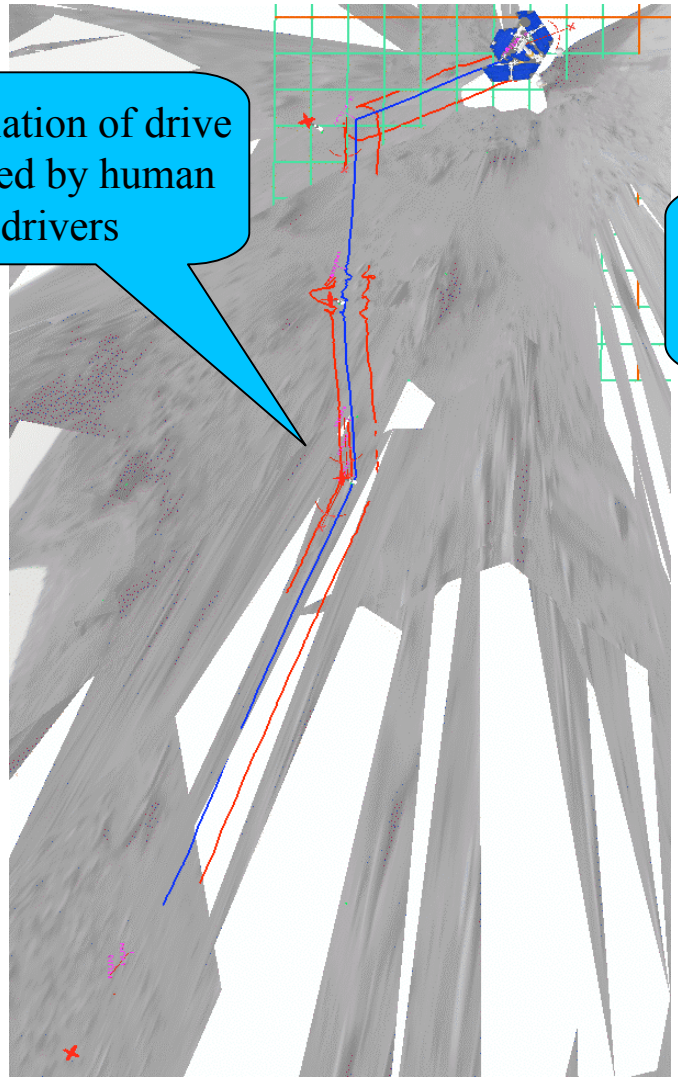


NASA/JPL/MSSS

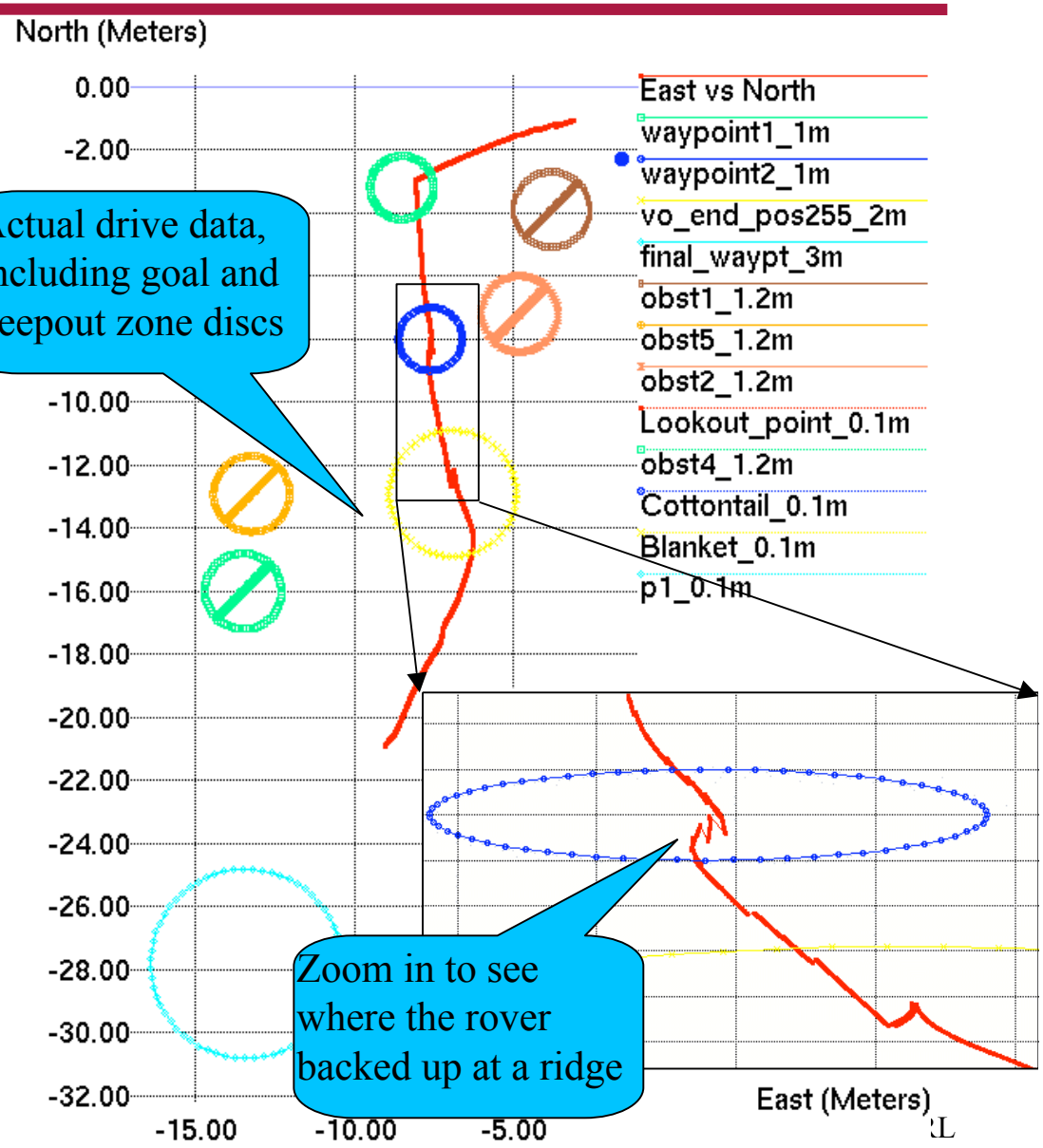
Inside Endurance Crater:

Six months of driving overlaid in one plot

Planned vs. Actual Drive: A-436



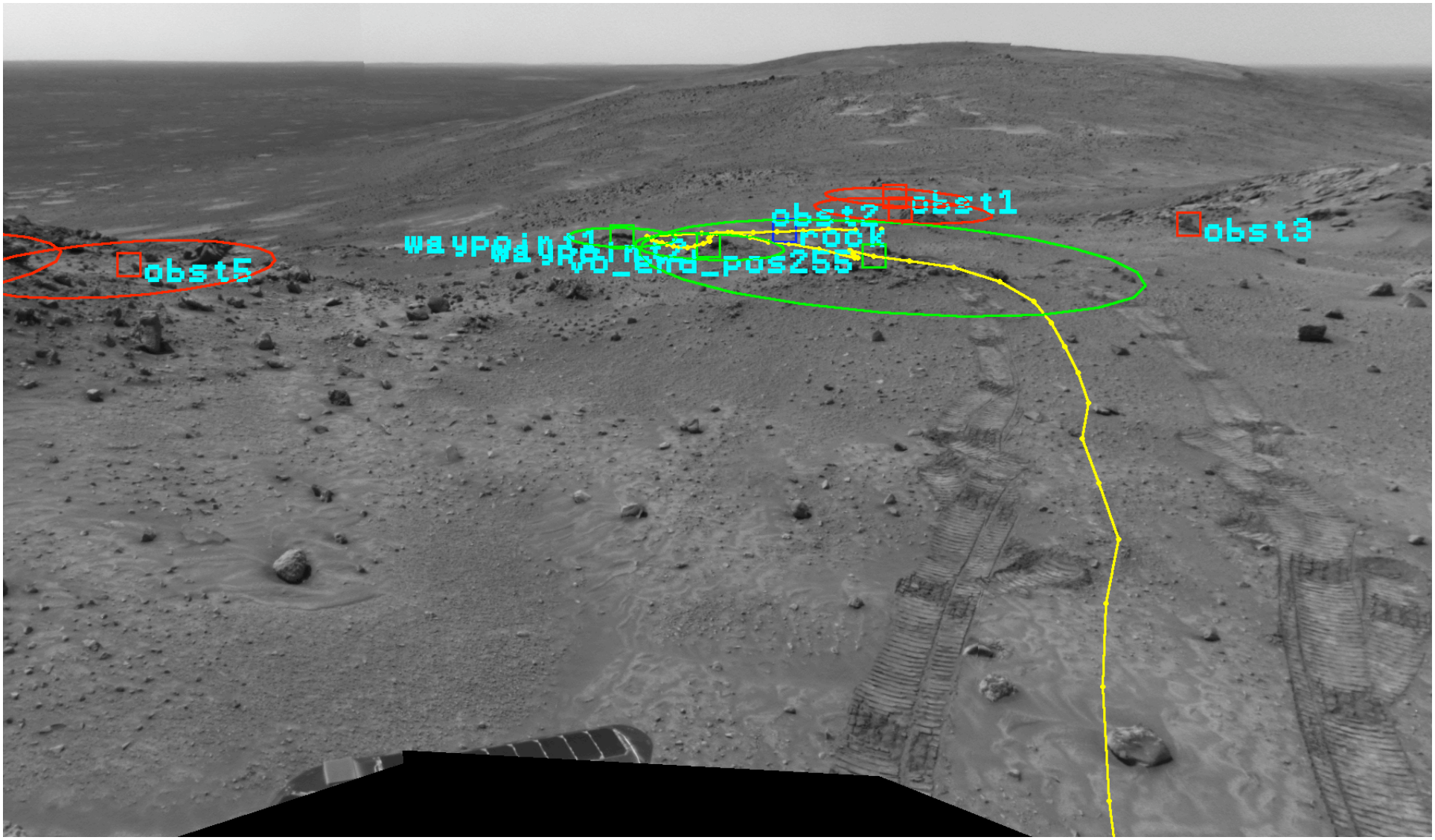
Simulation of drive planned by human rover drivers



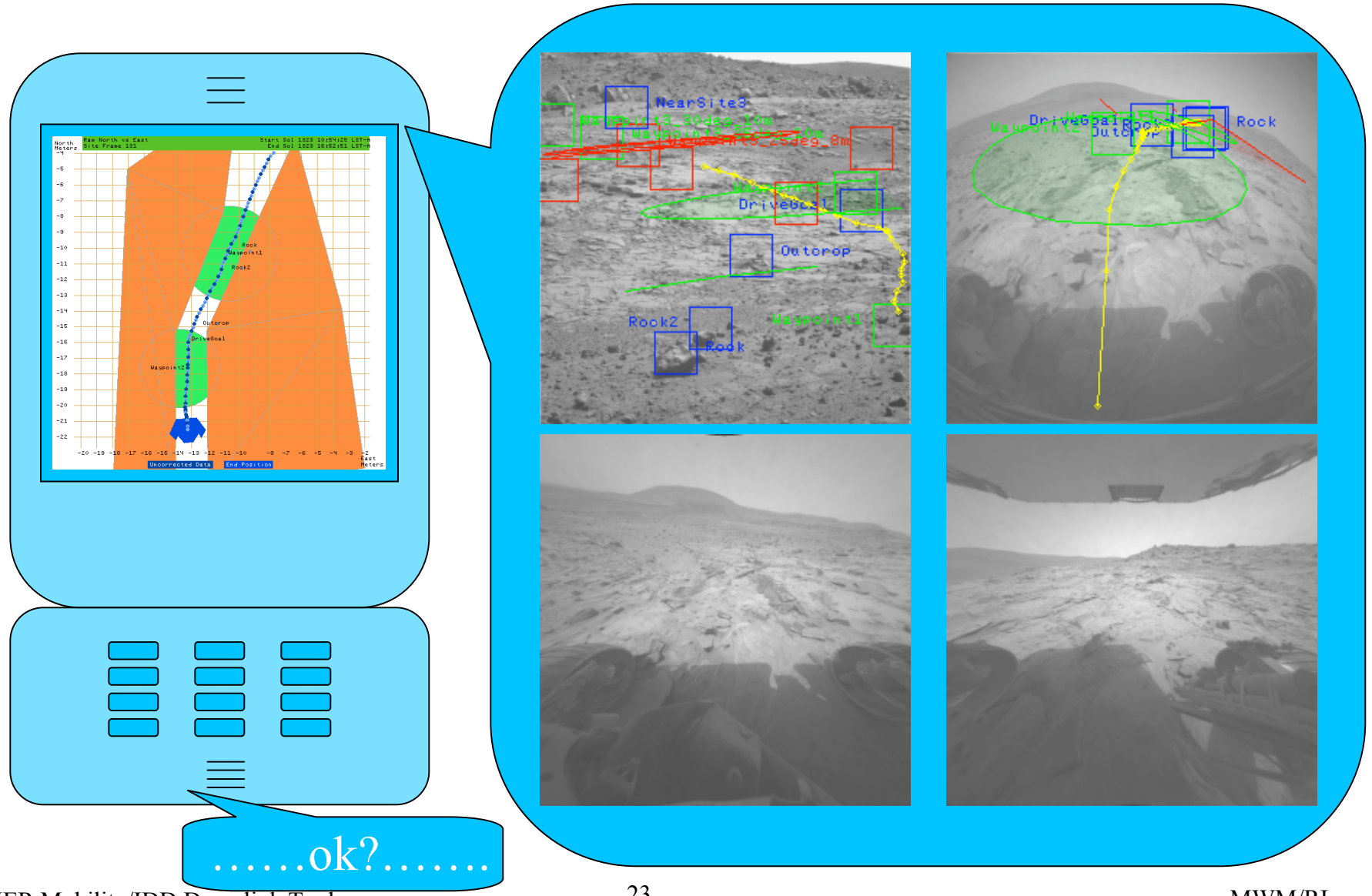
Actual drive data, including goal and keepout zone discs

Zoom in to see where the rover backed up at a ridge

Automatic Image Annotations



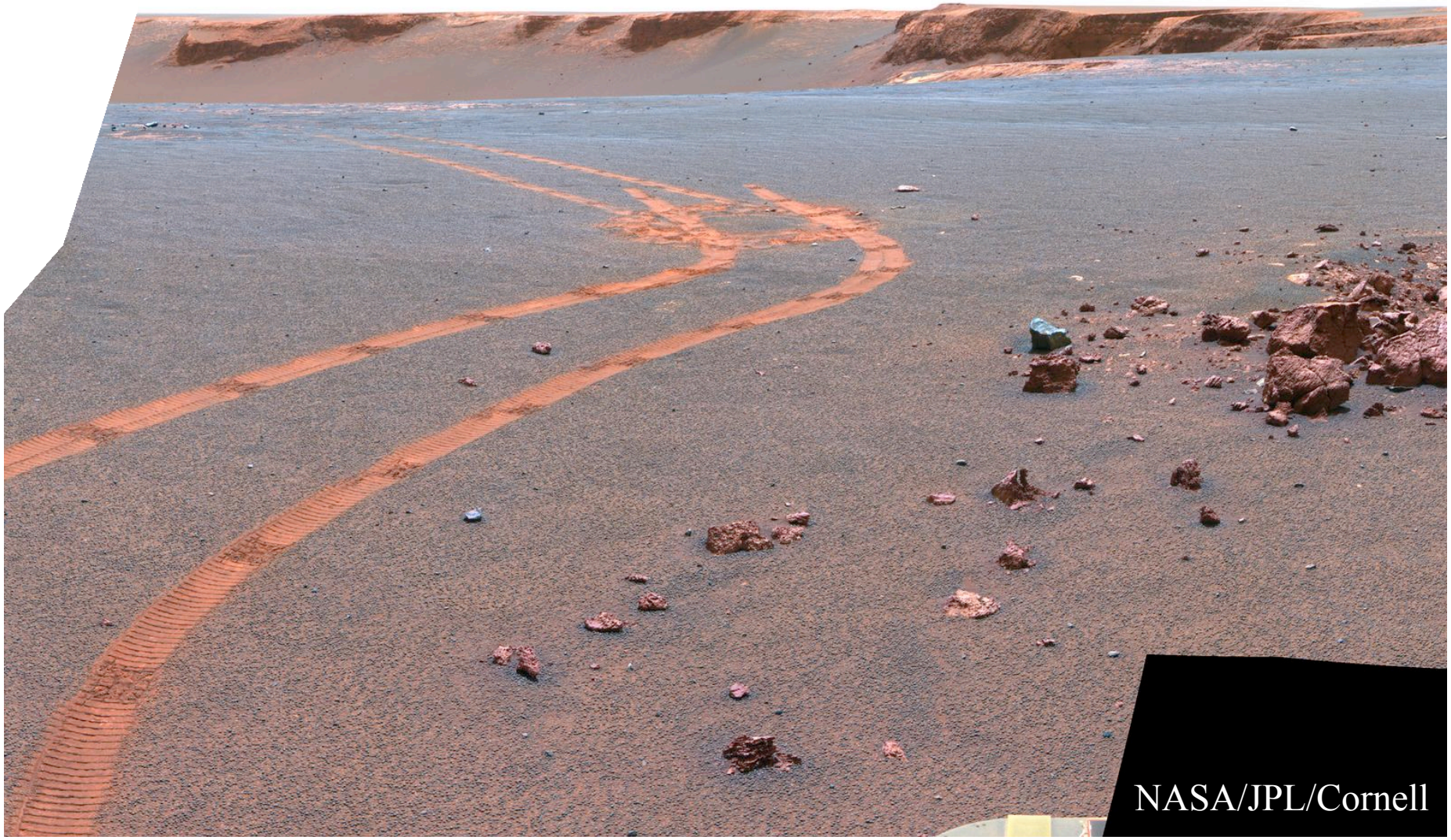
Cell Phone Updates



Lessons Learned

- **The onboard flight software needs to provide enough information to tie together the telemetry even when some is missing:**
  - Not only the timestamp of the data, but also information about which command generated it. Log what actually executed.
  - Use integer counters, and log them in many places, to track primitive motions (e.g., RMC Drive for wheels, RMC IDD for arm motions)
  - Use a catalogue of onboard data products to reason about what data has not been received yet.
- **Make data visualization tools endian-independent to enable their use on all workstations (e.g., PC/Linux vs. Sun machines)**
- **Provide consistent labels for all text message outputs (e.g., all "%d" format strings) and data product fields or you will have to hard-code their interrelationships later (e.g., X,Y,Z position in EVRs).**
- **Display data products and text messages within the list of commands that generated them, do not simply group them by their type.**
- **Use a common precision for timestamps.**

… Keep Exploring!



BACKUP SLIDES

MER Position Estimation

- MER vehicles were required to estimate position to within 10% precision over each 100 meters of driving.
- On flat terrain we use sensors with immediate feedback: Wheel Encoders (odometry) for position, very accurate LN200 Gyros for attitude, Accels for instantaneous tilt.
- On slippery sand, over loose rocks, at high tilt angles, the nominal position estimate's error can exceed 100%; so we process stereo NAVCAM images (45deg FOV, 20cm baseline, 1.5m elevation) in onboard *Visual Odometry* Processing
- Visual Odometry (*VisOdom*) automatically detects and tracks dozens of terrain features, and uses their motion to update the vehicle's position estimate onboard; no need for human input after the drive plan (including camera pointing) is set

Benefits of Visual Odometry

- VisOdom Increases Science Return
  - **Provides robust mid-drive pointing; even if you slip, the proper target can still be imaged**
  - **Enables difficult approaches to targets in fewer Sols; drive sequences conditional on position**
- VisOdom improves Rover Safety
  - **Keep-out zones; if you slide too close to known hazards, abort the drive**
  - **Slip checks; if you're not making enough forward process, abort the drive**

A-436: Exercising 3 Drive Modes

- The drive plan for Spirit's Sol 436 was:
  - **Back up 5m cross-slope**
  - **Drive upslope with VisOdom using 2 waypoints**
    - **Run Obstacle Check in parallel**
  - **Bear right and run AutoNav (no more VisOdom) to climb a reduced slope**
- One last note says:
  - ***This avoids the 25deg slopes along the front ledge on the upslope***